3.0 Program Development

This section summarizes the development of the UDWQ's public involvement, consultation, and coordination program—including the Steering Committee, the Science Panel, and a public involvement program—and the development of the overall selenium program (including analytical methodologies, a conceptual model for selenium in Great Salt Lake, threshold values, and the subsequent research program).

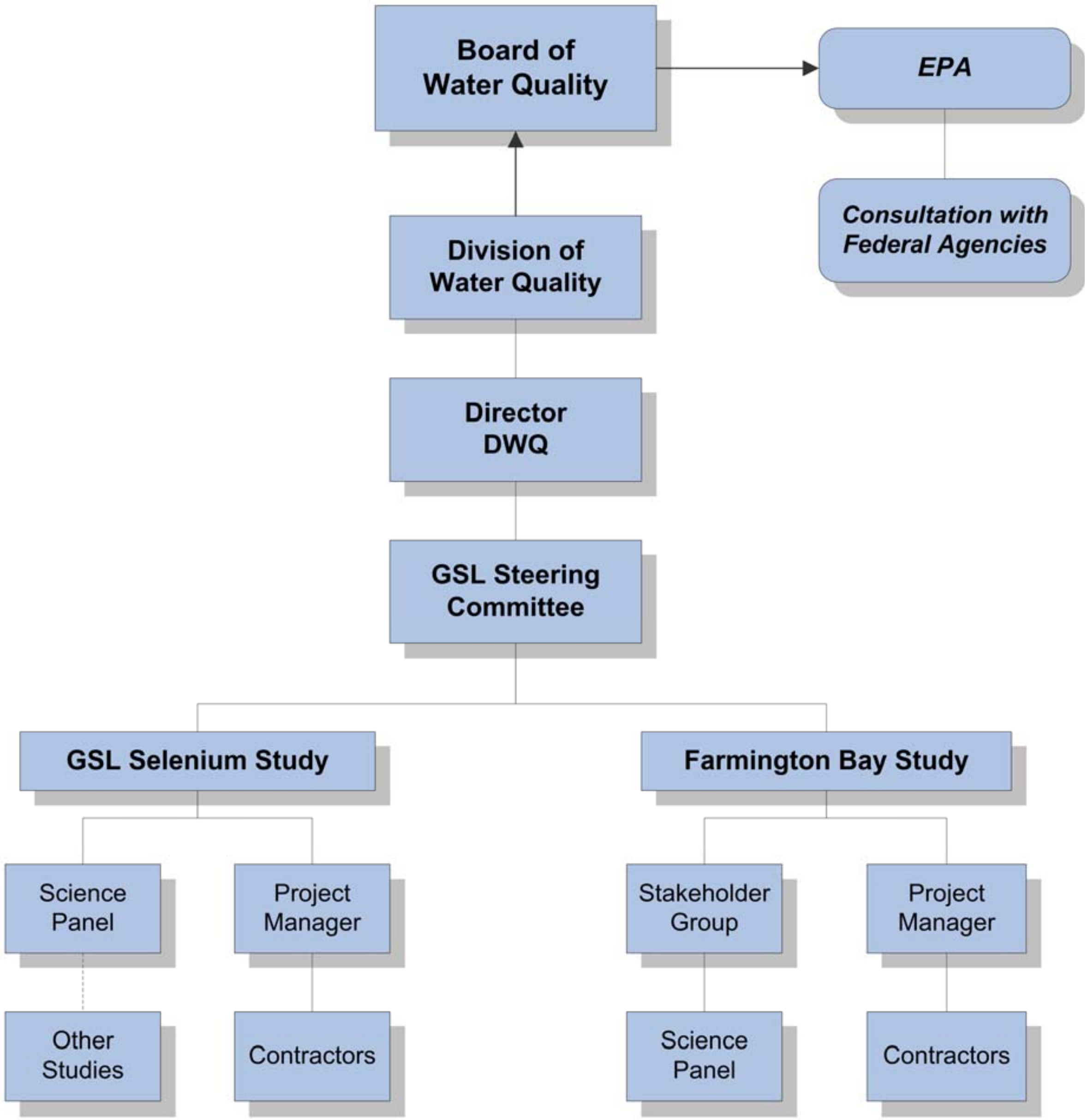
3.1 Public Involvement, Consultation, and Coordination

It was the objective of the UDWQ for the selenium program to be an inclusive and transparent process where input was actively solicited from a broad range of interests and incorporated into the decision-making process. Representatives from federal and state regulatory and resource agencies, other public entities, conservation organizations, recreation groups, and industrial users of the lake would not simply be informed of progress but would be actively involved in developing and recommending a new water quality standard to the State Water Quality Board. To that end, the UDWQ formed the Steering Committee and the expert Science Panel. These two groups were responsible for instituting and developing the selenium program described in this document. A public involvement strategy was integrated to also incorporate input from the general public.

3.1.1 Great Salt Lake Water Quality Steering Committee

The UDWQ formed the Steering Committee to recommend site-specific numeric water quality standards for Great Salt Lake to the State Water Quality Board. The standards are to be developed in such a way that they (1) prevent impairment of the lake's beneficial uses and (2) sustain the natural resources of the lake and associated wetlands (UDWQ, 2004a). The intent is for the Steering Committee to begin with the development of a water quality standard for selenium for the open waters of Great Salt Lake and then move to other constituents/contaminants as required. The Steering Committee currently also oversees a program to define and determine whether Farmington Bay's beneficial uses are impaired. Figure 3-1 illustrates the organizational structure for the Great Salt Lake Water Quality Studies program.

FIGURE 3-1
Organizational Structure



Members of the Steering Committee were originally identified by the UDWQ to represent the wide spectrum of interests in Great Salt Lake. The UDWQ worked with various prospective members to ensure the Steering Committee would fairly represent the broadest range of stakeholders. Table 3-1 identifies the 16 current members of the Steering Committee, their alternates, and the groups they represent. The Steering Committee had its first meeting on August 18, 2004, and has met at monthly or quarterly intervals as required since then. Steering Committee meeting dates, times, and locations were distributed to the members and posted on the Web site as soon as the dates were known, typically a month before the meeting. Meeting agendas and any related review materials were distributed via e-mail. An e-mail list (e-mail group that included the Steering Committee members and other interested individuals from the public) was established to facilitate the distribution of materials and communications. All meetings are advertised on the project Web site, announced to all interested stakeholders by e-mail, and open and free for the public to attend. Overall, 24 meetings were held throughout the selenium program from August 18, 2004 to May 2, 2008.

TABLE 3-1
Great Salt Lake Water Quality Steering Committee Members, their Affiliations, and Alternates

Members	Alternates
Dave Grierson Utah Department of Natural Resources/Forestry Fire and State Lands Representing State Government	No alternate designated
Clay Perschon Utah Department of Natural Resources/Division of Wildlife Resources Representing State Government	John Luft DNR/Division of Wildlife Resources Representing State Government
Karen Hamilton U.S. EPA, Region 8 Representing Federal Government	Jim Berkley U.S. EPA, Region 8 Representing Federal Government
Nathan Darnall U.S. Fish and Wildlife Service/Utah Field Office Representing Federal Government	Larry Crist U.S. Fish and Wildlife Service/Utah Field Office Representing Federal Government
David Naftz U.S. Geological Survey Representing Federal Government	Robert Baskin U.S. Geological Survey Representing Federal Government
Don Leonard Utah Artemia Association Representing Aquaculture	No Alternate Designated
Jim Huizingh Morton Salt Representing Industry	Tom Tripp US Magnesium, LLC Representing Industry
Kelly Payne Kennecott Utah Copper Representing Industry	Reed Bodell Kennecott Utah Copper Representing Industry
Richard Bay Jordan Valley Water Conservancy District Representing Municipalities	Mark Attencio Jordan Valley Water Conservancy District Representing Municipalities
Leland Myers Central Davis Sewer District Representing Publicly Owned Treatment Works	Jill Houston Central Davis Sewer District Representing Publicly Owned Treatment Works
Maunsel Pearce Great Salt Lake Alliance Representing Conservation Organizations	Chris Montague The Nature Conservancy of Utah Representing Conservation Organizations
Robert W. Adler Associate Dean for Academic Affairs Representing Conservation Organizations	Lynn de Freitas Friends of the Great Salt Lake Representing Conservation Organizations

TABLE 3-1
Great Salt Lake Water Quality Steering Committee Members, their Affiliations, and Alternates

Members	Alternates
Richard West West Side Associated Duck Clubs Representing Duck Clubs	Richard N. Gilbert Ambassador Duck Club Representing Duck Clubs
Delane McGarvey Representing Local Government	Florence Reynolds Salt Lake City Department of Public Utilities Representing Local Government
Richard Sprott Department of Environmental Quality Representing State Government	No Alternate Designated
Walt Baker DEQ/Division of Water Quality Representing State Government	No Alternate Designated

Source: *List of Great Salt Lake Steering Committee Members and Alternates*, September 11, 2007

The specific objectives of the Steering Committee are to (UDEQ, 2004a):

- Create a partnership among stakeholders, including industry, government agencies, and non-governmental organizations to:
  - Gain broad acceptance of process and results
  - Provide access to expertise and experience
  - Provide multiple funding sources
- Conduct a transparent public process by:
  - Identifying stakeholders
  - Receiving input
  - Sharing results
  - Seeking consensus
- Establish, at the beginning of the process, and maintain a scientific advisory panel to:
  - Identify gaps in scientific understanding of the lake chemistry and ecology
  - Advise the Steering Committee on funding applications
  - Prioritize water quality parameters of concern
  - Define and approve work plans for scientific studies
  - Provide for independent peer review of scientific studies
  - Recommend science-based numeric standards to the Steering Committee
- Sponsor and guide scientific research by:
  - Defining study objectives (for example, fate, bioaccumulation, toxicity)
  - Securing funding
  - Specifying or sponsoring development of appropriate study methods
  - Sponsoring data collection
  - Reporting results

- Adhere to federal and state statutes, regulations, and guidelines for standards development when:
  - Coordinating with EPA Region 8 on process for developing site-specific standards
  - Using results and recommendations of scientific research to determine appropriate numeric standards
  - Recommending numeric standards to Utah Water Quality Board for incorporation into the state Water Quality Administrative Rules

The Steering Committee works together using a consensus-building approach. A quorum is defined as two-thirds of the committee. A vote of two-thirds is required to accept procedural proposals and a supermajority of 75 percent is required for approval of proposals of a substantive nature. A supermajority of 75 percent of the committee is defined as a point where consensus has been achieved and is required for a recommendation to be forwarded to the Utah Water Quality Board. If a supermajority cannot be reached, then position papers for all opinions will be forwarded to the Utah Water Quality Board.

3.1.2 Science Panel

The Science Panel was formed by the Steering Committee to provide technical guidance, oversight, and review of required research for the selenium program, and recommend a water quality standard. While many members of the Steering Committee have significant technical expertise, the nine members of the Science Panel were carefully selected based upon their specific technical expertise and experience rather than the interests they represent. A core group of five panel members, including Dr. Joseph Skorupa/U.S. Fish and Wildlife Service, Dr. Theresa Presser/US Geological Survey, Dr. William Adams/Rio Tinto, Dr. Anne Fairbrother/Parametrix, Inc., and Bill Wuerthele, were selected based upon their national expertise and experience addressing selenium in aquatic ecosystems. The co-chairmen of the Panel, Dr. William Moellmer and Dr. Theron Miller—both representing the Utah Department of Environmental Quality—bring significant local experience with Great Salt Lake and state regulations. Dr. Don Hayes and Brad Marden also bring significant expertise of Great Salt Lake limnology, aquatic biology, and wetlands to the Science Panel.

The Steering Committee’s charge to the Science Panel is as follows (UDEQ, 2004c):

- Review goals, objectives, decision-making procedures, and Science Panel Charges, and recommend adjustments
- Review membership and recommend adjustments or additional expertise needed
- Prepare scope of work for a consultant/contractor to:
  - Gather and review existing literature on features of the Great Salt Lake ecosystem
  - Gather and review pertinent site-specific and outside data on ecotoxicology of selenium
  - Gather and review pertinent site-specific and relevant outside data to define the lake chemistry (for example, the chemistry and fate of selenium through the upper

water column, brine layer, sediment, atmosphere, and biota) and evaluate the potential variance associated with water levels and atmospheric conditions

  - Provide for independent peer review of scientific studies, as needed

- Identify gaps in scientific understanding that must be addressed to develop the standard
- Specify appropriate sampling and laboratory methodologies for selenium in Great Salt Lake, its tributaries, and discharges
- Prioritize other water contaminants of concern and suggest methods to include in present study, provided that such activities do not interfere with the development of a selenium standard
- Prioritize and recommend (to the Steering Committee) the research needed
- Assist the Steering Committee and the UDWQ in the following:
  - Selection of research contractors
  - Periodic review of contractors and work plans
  - Recommend atom of funding sources
- Interpret literature and results of site-specific scientific studies and agree on conclusions toward the standard
- Periodically report to the Steering Committee on progress and significant findings
- Recommend standard(s) to the Steering Committee
- Review and comment on methodologies and media needed for continued monitoring of selenium accumulation in the Great Salt Lake ecosystem

The Science Panel meeting dates were generally developed in coordination with the members, and dates, times, and locations were distributed to the Steering Committee and public as soon as the dates were known. Meeting agendas and any related review materials were distributed among the Science Panel via e-mail and the meeting agendas were distributed to the Steering Committee and public via e-mail. All meetings were advertised on the project Web site, announced to all interested stakeholders by e-mail, and were open and free for the public to attend. Science Panel meetings were often held in Salt Lake City with conference calls held monthly to facilitate project communication and coordination. Printouts of meeting handout materials were provided at each meeting. These materials were also posted on the Web site after the meeting. Throughout the selenium program, the Science Panel held 11 meetings and 17 conference calls from November 9, 2004 to May 2, 2008.

The Science Panel members determined that while they can and will address questions of a scientific nature, they cannot address questions of a philosophical or political nature. The Science Panel proposed to the Steering Committee, and received approval from the Committee at its March 21 through 23, 2007 meeting, to forward a recommended palette of values for a water quality standard to the Steering Committee to evaluate. The delivery of a range of values replaced the original intent of the delivery of one recommended specific value for a water quality standard. The palette will include pros and cons associated with each value to assist in the Steering Committee's deliberations.

The Science Panel works together using a consensus-building approach. If consensus cannot be reached, position papers for all opinions will be forwarded to the Steering Committee.

3.1.3 Public Involvement Program

Public involvement is a process by which interested and affected individuals, organizations, agencies, and government entities are consulted to participate in a decision-making process. Due to the complexity of issues involved in development of the selenium program and the diversity of interests with a stake in protection of Great Salt Lake, an extensive public involvement effort was conducted. The goal of this effort for the selenium program was to understand and address public concerns and issues and to develop the selenium program so that it addressed these concerns and issues.

To meet the goal of the public involvement effort, an open and objective approach to the selenium program was developed. Through a variety of public involvement activities, such as Steering Committee meetings, facilitating public participation in project meetings, and information materials, the State solicited public input for preparation of the selenium program. The public involvement approach developed for the selenium program was to facilitate a two-way exchange of information.

Overall, the approach to public involvement consisted of the following three main components:

- **The Steering Committee should address overall technical assumptions and policy issues.** The public involvement approach was integrated closely with the Steering Committee on overall technical assumptions and policy issues. The Steering Committee includes a diverse group of stakeholders from federal, state, and local regulatory, resource, and public agencies, as well as interested non-governmental organizations. The Steering Committee brings a diverse array of expertise and knowledge of different scientific and policy issues that may shape the selenium program.
- **Technical approach and deliberations should be open and transparent to the public.** Transparency and the ability to participate were essential in developing the public's trust in the integrity of the effort. The UDWQ facilitated the means for the public to be invited to and participate in all Steering Committee and Science Panel meetings and conference calls. All reference, planning, and work products were made available for public consumption after Science Panel review and acceptance.
- **Public outreach is vital in addressing local concerns and issues.** The public provides a unique view of the concerns and issues that may not be provided by other stakeholder groups. The public is generally concerned about a wide variety of issues, whereas stakeholder groups may be focused on a set of specific issues. Therefore, the means were implemented to solicit input from the general public. These means included public Steering Committee and Science Panel meetings, e-mailed updates and notices to a list of interested parties, meeting handouts, and extensive project materials made available on the Web site at www.deq.utah.gov/issues/GSL_WQSC/index.htm.

This open and objective approach sought to involve a diverse group of individuals in all aspects and levels of the development of the selenium program.

3.2 Program Development

Figure 3-2 summarizes the process the Steering Committee developed for the selenium program (UDWQ, 2004d). Dates on this chart were updated to reflect the most recent available information. As previously discussed and illustrated in Figure 3-2, significant interaction between the Steering Committee, the Science Panel, and investigators was critical in developing and completing the aggressive program. An extensive program of research projects was envisioned to serve as the basis for the water quality standard; however, two tasks were identified as essential preliminary steps for the foundation of those projects: (1) development of analytical methodologies and (2) development of a conceptual model that characterizes selenium cycling in the open waters of Great Salt Lake. Subsequently, toxicity threshold values were developed in conjunction with the projects to frame the palette of values for the water quality standard that would be evaluated. This section describes the development of these three tasks and how they were used to shape the projects completed as part of the research program.

3.2.1 Analytical Methodologies

Various analytical methods have historically been used for analysis of water from Great Salt Lake. Recent analytical results for selenium have ranged from about 1 µg/L using hydride generation atomic absorption (HGAA) spectrometry to about 120 µg/L using graphite furnace atomic absorption (GFAA) spectrometry. Much of the variability is likely from interferences caused by the extreme salinity, high and variable total dissolved solids (TDS), and alkaline nature of Great Salt Lake waters. A practical analytical method that met sensitivity criteria, required minimal sample dilution, tolerated high TDS, minimized spectral interferences, and was simple and reliable was needed to help establish a baseline of selenium data for Great Salt Lake.

Under the direction of the Science Panel, UDWQ initiated a round-robin study among seven laboratories in 2004 to compare ambient selenium concentrations and low-level spike recoveries in Great Salt Lake water. This round-robin study is described in detail by Moellmer et al. (2007). Sample water from Great Salt Lake was collected from depths of 1 meter and 7 meters and filtered using a 0.45-micrometer membrane filter. Samples were sent to a third-party laboratory for preparation of replications and spiking. A total of 36 samples were sent to each of seven laboratories that used different analytical methods including conventional inductively coupled plasma—mass spectrometry (ICP-MS), passive and dynamic collision/reaction cell ICP-MS, octopole reaction cell ICP-MS (ORC ICP-MS), GFAA, and HGAA.

Two methods, HGAA and ORC ICP-MS, provided results that were adequately consistent and accurate as determined from spike recoveries. The other methods yielded significant positive bias and unusable results. As a result, the Science Panel identified HGAA as the only current method suitable for use in the selenium program. ORC ICP-MS is another possible method that may be used but will require further evaluation. Further, the Science Panel asked that all historic Great Salt Lake selenium water quality data that were not developed using HGAA or ORC ICP-MS be evaluated and potentially qualified as unsuitable for use. The Science Panel asked that water samples collected as part of the selenium program be analyzed using HGAA.

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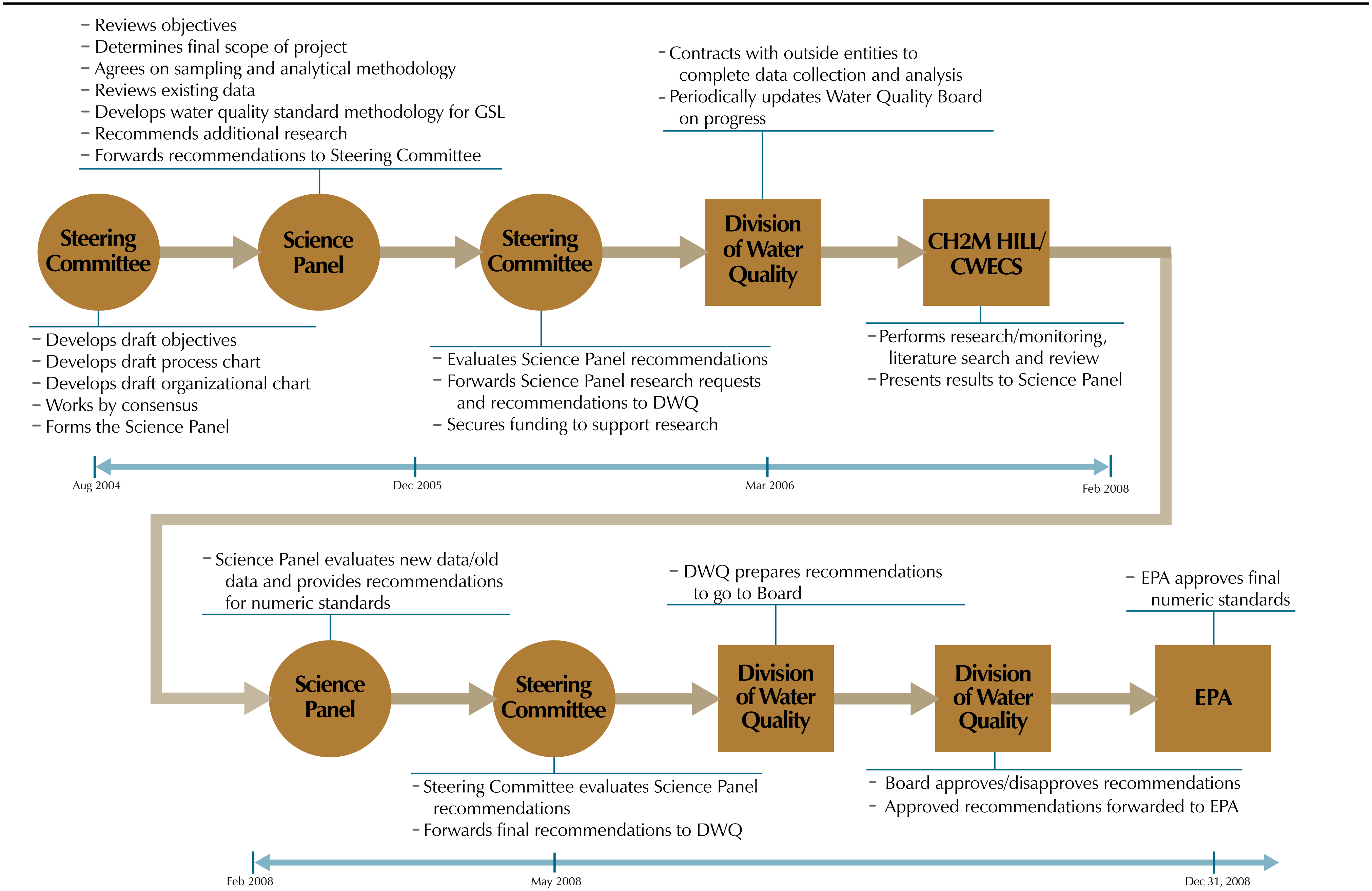

FIGURE 3-2
Process Chart for the Selenium Program
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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3.2.2 Conceptual Model

An essential element to understanding the cycling of selenium in the Great Salt Lake ecosystem is the development of a conceptual model. The purpose of the conceptual model is to qualitatively illustrate the physical processes and relationships regulating the movement of selenium through the ecosystem. It provides a visual representation of Great Salt Lake's cause-and-effect relationships that is useful for identifying those areas where more study is required. The Science Panel's objective was to develop a conceptual model that would assist them in defining research projects and serve as the basis for a quantitative model describing the system.

The Science Panel worked with Drs. Bill Johnson, Mike Conover, Wayne Wurtsbaugh, and Jack Adams to develop the Conceptual Model for Selenium Cycling in Great Salt Lake (Johnson et al., 2006). That report is included in Appendix A for reference. It used available information to characterize selenium cycling in Great Salt Lake, summarize the trophic transfer of selenium through the food chain, and describe the biogeochemical cycling of selenium below the food chain. The conceptual model was divided into five components: (1) selenium in the upper food chain, (2) selenium in the lower food chain, (3) selenium in the shallow layer of Great Salt Lake, (4) selenium in the deep layer and sediment, and (5) selenium in the water as characterized by loading to the lake. Each component was illustrated with a qualitative flow chart and included accompanying text summarizing the underlying assumptions and supporting references. The draft final version of this conceptual model served as the basis for the Science Panel's understanding of Great Salt Lake selenium cycling, identification of projects to be conducted, and an understanding of the endpoints that might be used for the development of a water quality standard.

A simplified conceptual model was developed with the Science Panel in October 2006 to characterize these critical endpoints and the elements of the original conceptual model that the selenium program would focus upon in defining quantitative relationships (such as transfer of selenium through the food chain). Figure 3-3 illustrates the simplified conceptual model and includes only three main components rather than the original five: (1) selenium in the upper food chain, (2) selenium in the lower food chain, and (3) selenium in the water and sediment. This revised model was used by the Science Panel to integrate results of the research completed for the selenium program and to develop quantitative relationships among individual components of the ecosystem.

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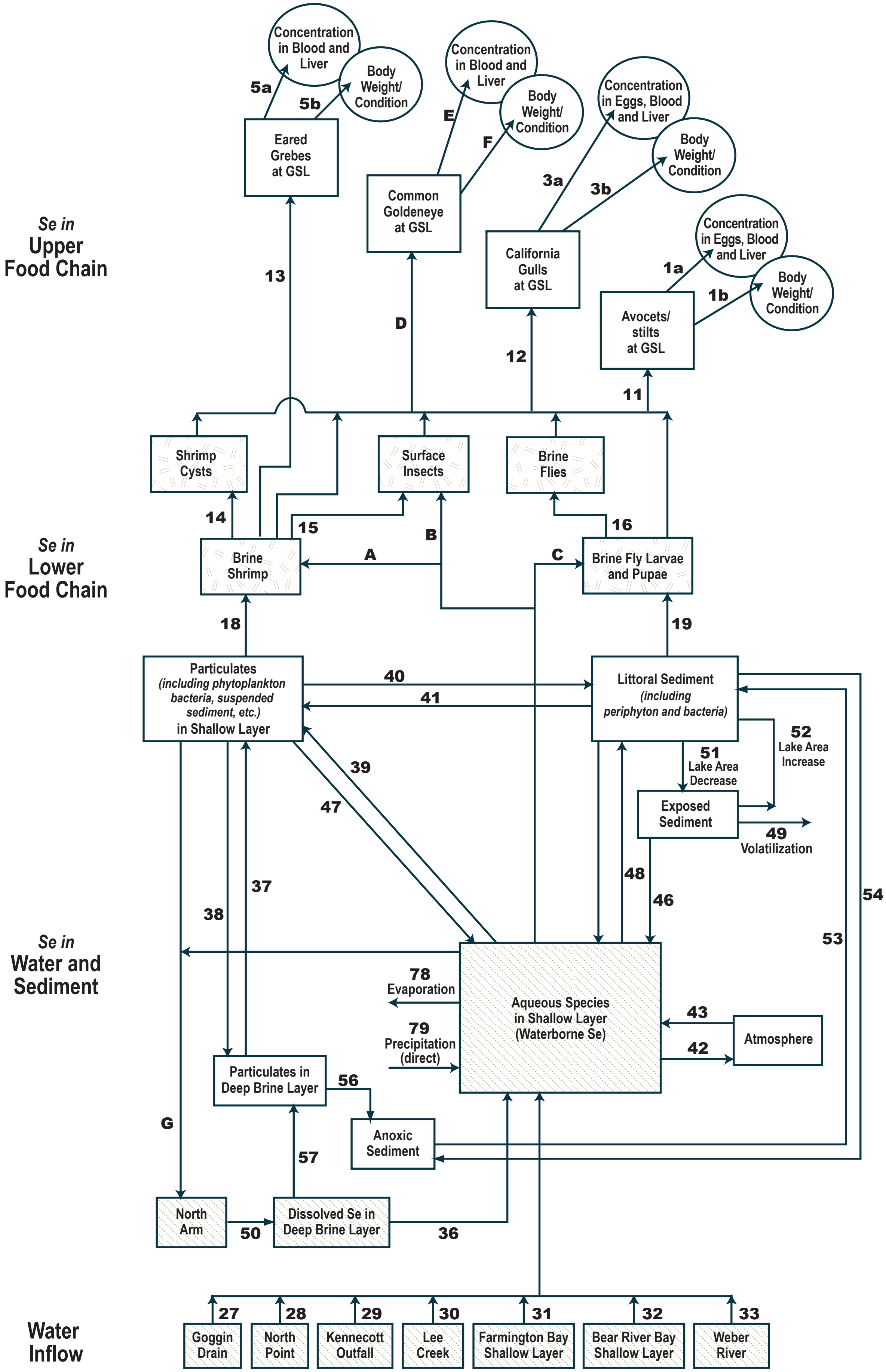

WB042008002SLC GSL_Delineation-of-Projects.ai

FIGURE 3-3
Simplified Conceptual Model for Selenium Cycling
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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3.2.3 Toxicity Threshold Values

3.2.3.1 Critical Endpoints

It is generally recognized that the most significant exposure of birds to selenium occurs through their diet and that the best-documented and most readily monitored effects are those on reproductive success (particularly egg hatchability). The conceptual model (Johnson et al., 2006) suggested various species of birds that are known to breed on Great Salt Lake (for example, black-necked stilt, American avocet, Franklin's gull, California gull, and snowy plover). The conceptual model also suggested that various species of birds (for example, eared grebe, northern shoveler, and common goldeneye) feed extensively on the open water during migration or while overwintering on Great Salt Lake but do not breed on Great Salt Lake. The sensitive endpoint for these birds was surmised to be mass wasting that would inhibit successful migration or survival during the winter months. The Science Panel agreed that bird diet (brine shrimp and/or brine flies) was the key pathway to the two most sensitive, or critical, endpoints in birds that depend on the open waters of Great Salt Lake: (1) reproductive success and (2) body condition. These critical endpoints (particularly reproductive success) were the focus of the research conducted during 2006 and 2007, and the more sensitive and more readily monitored of the two represents what the water quality standard will be developed to protect, as described in the following sections.

3.2.3.2 Development of Threshold Values

Toxicity threshold values for the exposure of birds to selenium at Great Salt Lake are necessary for the development of a water quality standard that is protective of these endpoints. A toxicity (or threshold) value is defined as the exposure level or dose of a substance above which toxicity or adverse effects can occur, and below which toxicity or adverse effects are unlikely to occur. The threshold value for the birds' diet as well as bird tissue (for example, in eggs) determines the protective limit for selenium in these endpoints. These values were evaluated as part of the overall conceptual model to determine what selenium concentrations in the water column would be protective of those threshold values. The Science Panel identified the following key considerations for the threshold values:

- It is generally recognized that the most significant exposure of birds occurs through their diet.
- The best-documented and most readily-monitored effects are those on reproductive success (particularly egg hatchability, assessed indirectly for Great Salt Lake on the basis of selenium concentrations in food-chain organisms and bird eggs).
- Laboratory studies with mallards provide the best available data to evaluate avian exposure and effects; because the mallard is relatively sensitive to the effects of selenium, using those threshold values builds in conservatism so that the result can be considered protective of other species.
- The 95 percent confidence interval (CI) on the mean selenium concentrations in mallard diet and eggs associated with the 10 percent effect concentration (EC_{10}) for egg hatchability (explained in the following paragraphs) defines a range of values that would be reasonably protective for birds nesting at Great Salt Lake.

- Two technical memoranda in Appendix B provide a summary and discussion of potential threshold values identified by Science Panel members for consideration in establishing a water quality standard for selenium in the open waters of Great Salt Lake.
- The degree of protectiveness to be applied by the State in setting the water quality standard is not known, and there is not complete understanding of the sensitivity of the Great Salt Lake system to selenium; thus, the Science Panel identified a range of values to be used in modeling and derivation of a potential standard

From the available information, the Science Panel initially (in November 2006) narrowed the values to be considered by identifying "working values" for the ranges of acceptable selenium concentrations in bird diets and eggs. For both diet and eggs, the Science Panel selected the ranges of selenium concentrations provided by Ohlendorf (2003); they include the 95 percent CI (also referred to as the 5 percent lower confidence limit [LCL] and the 95 percent upper confidence limit [UCL]) for the mean selenium concentration that is associated with a 10 percent reduction (that is, EC_{10}) in the hatchability of mallard eggs. While the U.S. Fish and Wildlife Service is no longer able to respond in writing to requests for species lists and concurrence with "no effect" determinations, no federally listed threatened and/or endangered species are known to use the open waters of Great Salt Lake (Nathan Darnall, personal communication with Bill Moellmer, October 4, 2007).

For bird diets, the 95 percent CI is from 3.6 to 5.7 mg Se/kg (mean equals 4.9 mg Se/kg); in bird eggs, the 95 percent CI is from 6.4 to 16 mg Se/kg (mean equals 12 mg Se/kg) (all concentrations in bird diets or eggs mentioned in this document are expressed on dry-weight basis). Those values were based on the analysis of data from six laboratory studies (Heinz et al., 1987, 1989; Heinz and Hoffman, 1996, 1998; Stanley et al., 1994, 1996). Essentially, there is 95 percent confidence that the mean dietary or egg selenium concentration that causes a 10 percent reduction of egg hatchability is within the identified ranges, which are illustrated in Figures 3-4 and 3-5.

FIGURE 3-4
Mallard Egg Hatchability versus Control as a Function of Selenium Concentration in Diet

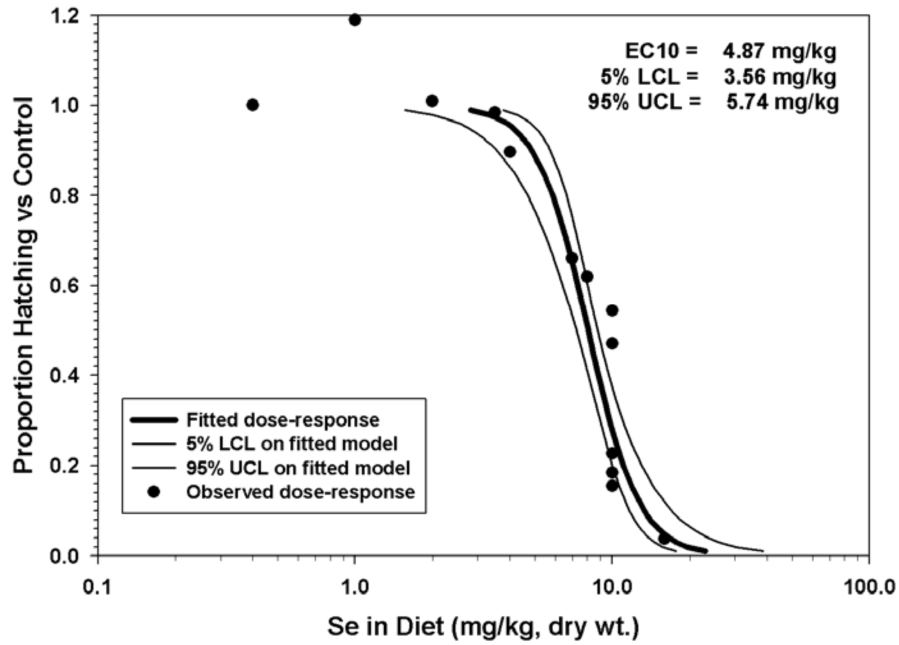
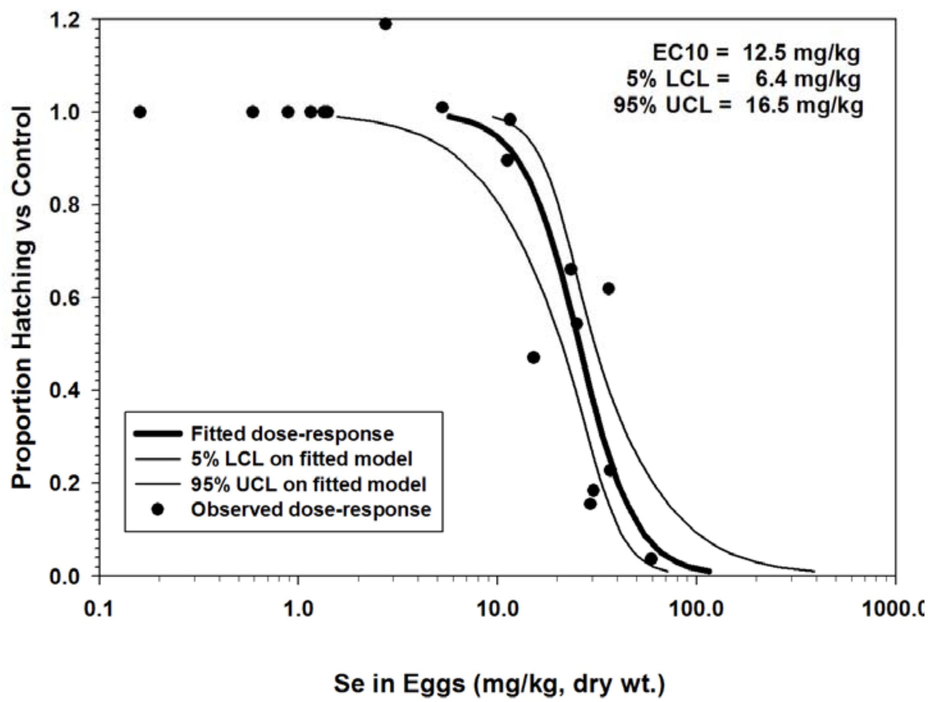


FIGURE 3-5
Mallard Egg Hatchability versus Control as a Function of Selenium Concentration in Eggs



At the July 31 to August 1, 2007 Science Panel meeting, Joe Skorupa suggested an alternative method of communicating the selected threshold values that de-emphasizes the EC_{10} terminology. Those values (shown in Table 3-2) relate the mean, LCL, and UCL as a selenium concentration in the diet or in bird eggs to the degree of reduction in egg hatchability (as percent reduction) associated with those selenium concentrations. For each concentration, the table lists the "maximum likelihood" value that is the best estimate of the expected decrease in hatchability. The table also lists the reduction in hatchability that can be expected to occur (as the best estimates of best case and best estimates of worst case) for the corresponding concentrations. The best case and worst case estimates are the range of the absolute least to the absolute most reduction that is associated with the Selenium concentration, with 95 percent confidence that the level of effect falls within that range. In each case, the probability of the extremes occurring is very low.

Se Concentration (mg Se/kg)	Best Estimate of Reduction in Hatchability		
	Best Case	Maximum Likelihood	Worst Case
Diet			
3.6	<1%	3%	10%
4.9	4%	10%	24%
5.7	10%	18%	32%
Egg			
6.4	<1%	1.5%	10%
12	3.5%	10%	26%
16	10%	21%	38%

The Science Panel requested that the upper and lower 95 percent CI as well as the mean value for the EC_{10} initially be used in the development of the quantitative model of the ecosystem. Using the upper and lower bounds of the accepted range would assist the Science Panel in evaluating the sensitivity of Great Salt Lake to selenium.

3.2.3.3 Basis for Selection of Threshold Values

As previously mentioned, the dietary selenium EC_{10} for mallards was reported as 4.9 milligrams per kilogram (mg/kg), with 95 percent CI of 3.6 to 5.7 mg/kg based on reproductive toxicity (egg hatchability) (Ohlendorf, 2003). The EC_{10} was estimated by fitting a logistic regression model (Figure 3-4). Similar to the dietary values calculated by Ohlendorf (2003) for reproductive toxicity for mallards, the EC_{10} in eggs was reported as 12.5 mg/kg, with 95 percent CI of 6.4 to 16.5 mg/kg (Figure 3-5). This EC_{10} also was estimated by fitting a logistic regression model to the results of the six laboratory studies with mallards.

Other statistical methods and adjustments were discussed by the Science Panel; however, the consensus was that this range of values, as defined by Ohlendorf, would be used for consideration of the water quality standard.

3.2.4 Research Program

Using the draft final version of the conceptual model (Johnson et al., 2006), the Science Panel derived the following nine priority projects to assist in furthering their understanding of selenium cycling in Great Salt Lake and to develop their recommendation for a selenium water quality standard:

- Identify bird species breeding on the lake; identify nesting populations and locations
- Analyze remaining water samples archived at the USGS
- Develop a request for proposals (RFP) to collect eggs for breeding birds (for example, black-necked stilts, American avocets, shovelers, etc.); complete synoptic survey of the lake to sample brine flies and brine shrimp
- Develop an RFP to synthesize available selenium data for water, biota, and sediments of Great Salt Lake
- Develop an RFP to determine the mass load of selenium to Great Salt Lake (for example, characterize flows and water concentrations for main sources of water to the lake)
- Develop an RFP to determine the fate of selenium in Great Salt Lake (for example, define the transfer to the sediments and flux from sediment to and from the water column)
- Review the existing conceptual model and evaluate the need to expand it
- Develop a report summarizing the round-robin study
- Evaluate the need to sample eared grebes in the fall

This list was condensed by the Science Panel into the following four projects that were issued in an RFP in January 2006:

- **Project 1**—Determine ambient selenium concentrations in water, brine shrimp, brine flies, and bird eggs; determine stomach contents of nesting birds
- **Project 2**—Design and conduct a selenium concentration synoptic survey in the water and brine shrimp within Gilbert Bay
- **Project 3**—Determine selenium loadings from point sources and rivers to Gilbert Bay of Great Salt Lake
- **Project 4**—Develop a selenium transfer/flux model between the sediments and water column

The specific objectives and workplans for each project were the subject of significant discussion during the first quarter of 2006. While the intent of each project largely remained the same, the methods, media to be sampled, and period of sampling were adjusted based upon additional information and suggestions provided by the principal investigators and discussion with the Science Panel. The final objectives and workplans are summarized in Section 4.0 and are included in CH2M HILL's 2006 *Selenium Program Manual* and on the Web site. The four projects evolved into the six projects started in 2006 as described in the following paragraphs. Figure 3-6 illustrates the relationship between the six projects and the simplified conceptual model.

- **Project 1A**—Determine the concentration and effect of selenium in shorebirds through the sampling of adult birds, eggs, diet, water, and sediment
- **Project 1B**—Determine the concentration and effect of selenium in California gulls through the sampling of adult birds, eggs, diet, water, and sediment; determine the concentration and effect of selenium in eared grebes and common goldeneyes through the sampling of adult birds when they arrive at Great Salt Lake and prior to leaving the lake
- **Project 2A**—Synoptic survey of selenium in periphyton and brine fly larvae from the benthic zone
- **Project 2B**—Synoptic survey of selenium in water, seston, and brine shrimp from the pelagic zone
- **Project 3**—Measurement and modeling of selenium loads to Great Salt Lake
- **Project 4**—Measurement of selenium flux to and from sediment and atmosphere

A review of initial data collected for each of the projects in 2006 identified the need for additional studies. The Science Panel requested, and the Steering Committee approved, the following study objectives for 2007:

- **Project 1A**—Repeat a subset of the 2006 sampling program in 2007 with the addition of analysis for mercury
- **Project 1B**—Repeat a subset of the 2006 sampling program in 2007 with the addition of analysis for mercury and the sampling of a gull colony at a freshwater location
- **Project 2B**—Continue 2006 sampling program through July 2007
- **Project 4, Volatilization**—Directly measure volatilization on the open waters of Great Salt Lake to verify estimates
- **Project 4, Sedimentation**—Collect additional shallow and deep sediment cores to verify sedimentation rates and permanent burial of selenium in sediment
- **Project 5**—Complete kinetic studies in the laboratory to define the transfer of selenium from water and diet to brine shrimp

Further, the Science Panel requested, and the Steering Committee approved, the integration of data and observations from these projects into a quantitative model and report as described in this document.

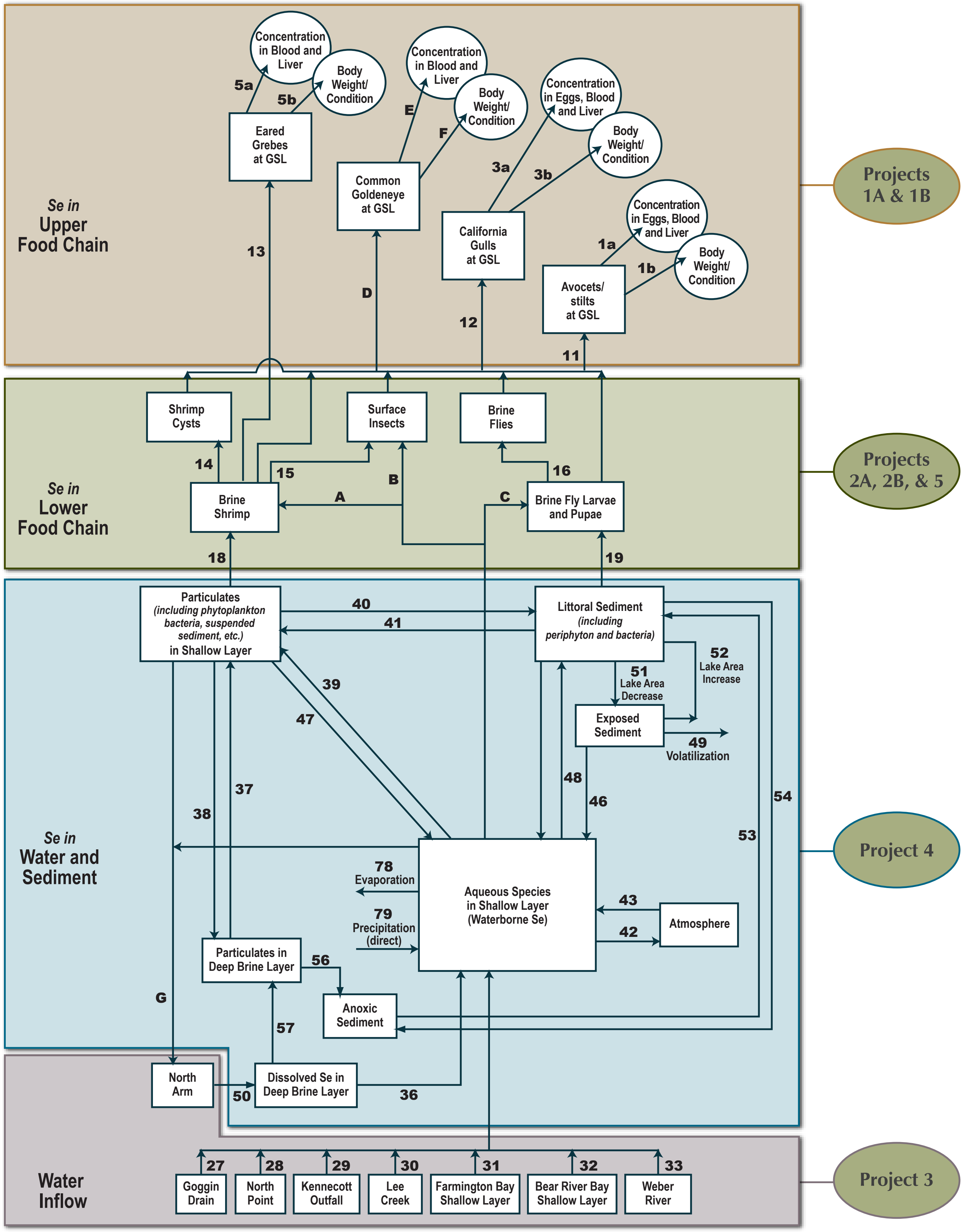


FIGURE 3-6
Delineation of Projects within the Conceptual Model
Great Salt Lake Water Quality Studies
Draft Report – Selenium Program

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4.0 Program Objectives

This section defines the objectives for the overall selenium program and for each of the individual projects.

4.1 Program Objectives

The UDWQ's objective is to define a site-specific, numeric water quality standard for selenium that prevents impairment of the beneficial uses of the open waters of Great Salt Lake. This was to be accomplished through the development of a selenium study program intended to enable the Steering Committee to recommend a standard to the Utah Water Quality Board. As such, the selenium program was designed to complete the appropriate studies (identified by the Science Panel) and evaluation needed to support such a recommendation.

4.1.1 Data Quality Objectives

The EPA has prepared a data quality objectives (DQOs) process (EPA, 2000, 2006) that serves as a useful tool in assessing what questions must be answered (or decisions that need to be made), what information is available to answer those questions, what additional information is needed, how that information will be collected, and how it will be used in making decisions as related to development of a selenium standard for the open waters of Great Salt Lake. Implementation of the DQOs process in the selenium program, along with use of the previously developed conceptual model, helped describe how the physical, chemical, and ecological components of the environment are related, as well as provided the rationale and context for the work that would be done. The DQOs described the objectives and overall approach for conducting studies to support development of the standard and provided more specific information about the work to be done under each of the individual projects. The DQOs developed for the program and for each of the original six projects active in 2006 are included in the Program Manual; DQOs were developed subsequently for the laboratory kinetic studies with brine shrimp. The listed questions and objectives posed in each project's DQOs are included in the following sections.

4.1.2 Program Questions

The central question for the selenium program to resolve can be stated as follows:

- What is the acceptable waterborne concentration of selenium that will prevent impairment of the beneficial uses of the open waters of Great Salt Lake?

More specific questions that support this overall decision were developed to help define the individual projects completed as part of the program. Figure 4-1 illustrates how these questions relate to the development of the program's seven projects.

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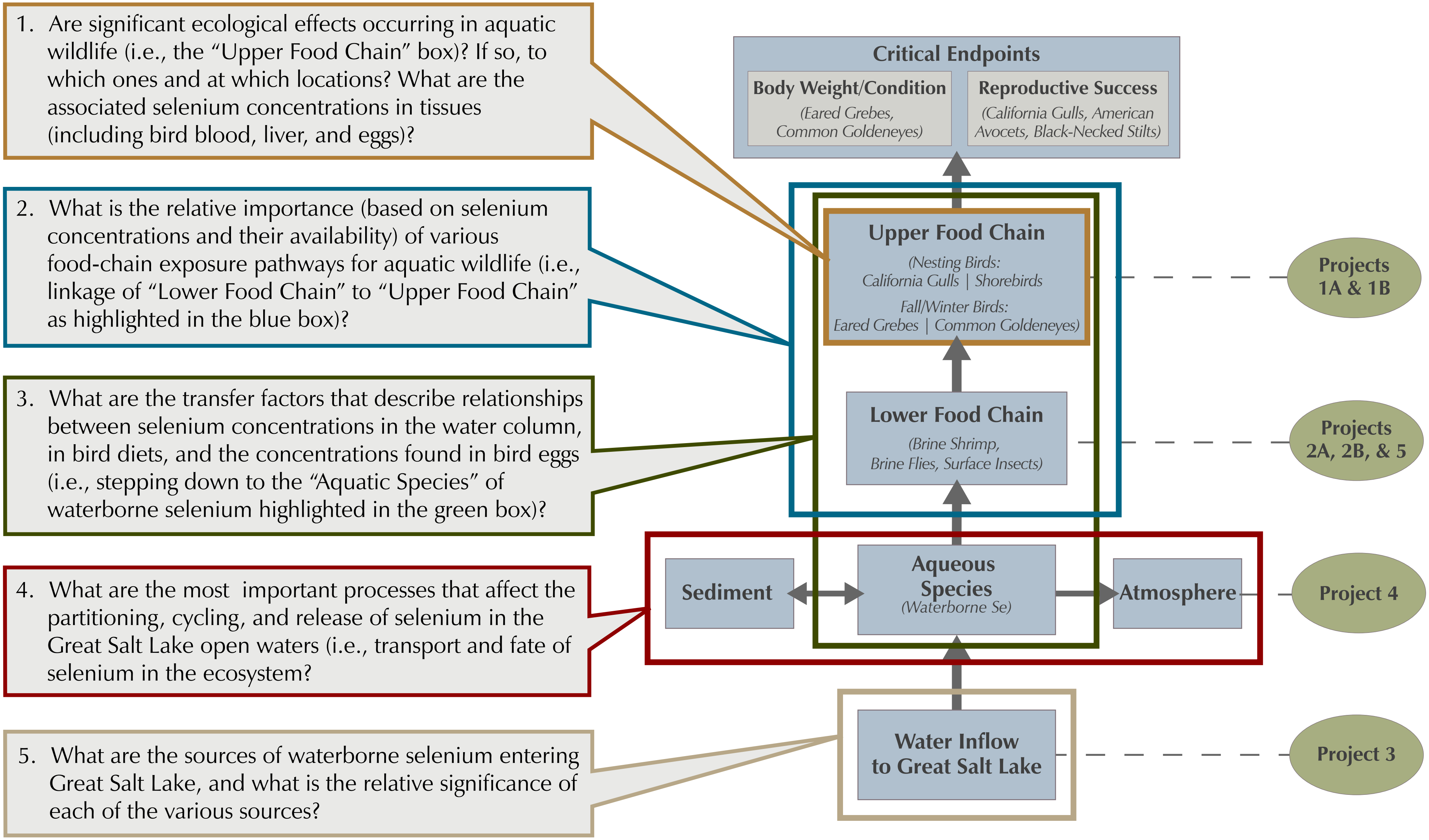

FIGURE 4-1
Program Questions Relative to Projects
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2 Project Objectives

As described in Section 3.0, each of the selenium program's studies was initially identified and prioritized by the Science Panel through an evaluation of the conceptual model, available information, and discussion with principal investigators. A key element in developing and refining the work plan for each project was definition and discussion of each project's objectives and targeted questions to be answered. The project's DQOs, work plan, and standard operating procedures (SOPs) were subsequently developed and revised per Science Panel input. This section summarizes the objectives and questions for each project, and it illustrates which components of the conceptual model were to be addressed by each project.

Project DQOs, workplans, and SOPs for the six initial projects are included in the *Selenium Program Manual*. Detailed discussion of project background, objectives, methods, and results are found in each project's final report, and included in Appendices C through I of this document.

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4.2.1 Project 1A, Concentration and Effects of Selenium in Shorebirds

Principal Investigator: Dr. John Cavitt, Weber State University

Project Objectives (2006)

- Determine ambient selenium concentrations in water, sediment, brine shrimp, brine flies, and unidentified food items in nesting shorebird foraging areas, bird eggs, bird blood, and bird livers
- Determine stomach contents of nesting birds
- Determine if selenium concentrations affect reproductive success of American avocets and black-necked stilts at Great Salt Lake

Project Objectives (2007)

- Determine ambient selenium concentrations in brine fly larvae and in American avocet eggs
- Determine stomach contents of nesting birds
- Verify 2006 selenium concentrations by determining selenium and mercury concentrations in nesting American avocet blood and liver

Project Questions

The guiding questions for Project 1A include the following:

- What do the shorebirds eat at Great Salt Lake, and what are the transfer factors for selenium from the diet to bird eggs?
- Are significant ecological effects occurring in American avocets and black-necked stilts? If so, to which ones and at which locations?
- What are the associated selenium concentrations in bird eggs, blood, and liver?

To understand the potential effects of selenium on shorebirds at Great Salt Lake, the following questions needed to be addressed:

- What is the diet of American avocets and black-necked stilts at Great Salt Lake?
- What is the ambient concentration of selenium in the water and macro-invertebrates consumed by shorebirds?
- What is the concentration of selenium within the liver and blood of American avocets and black-necked stilts?
- What is the concentration of selenium within the eggs of American avocets and black-necked stilts?
- What is the hatching success of American avocet and black-necked stilt eggs?

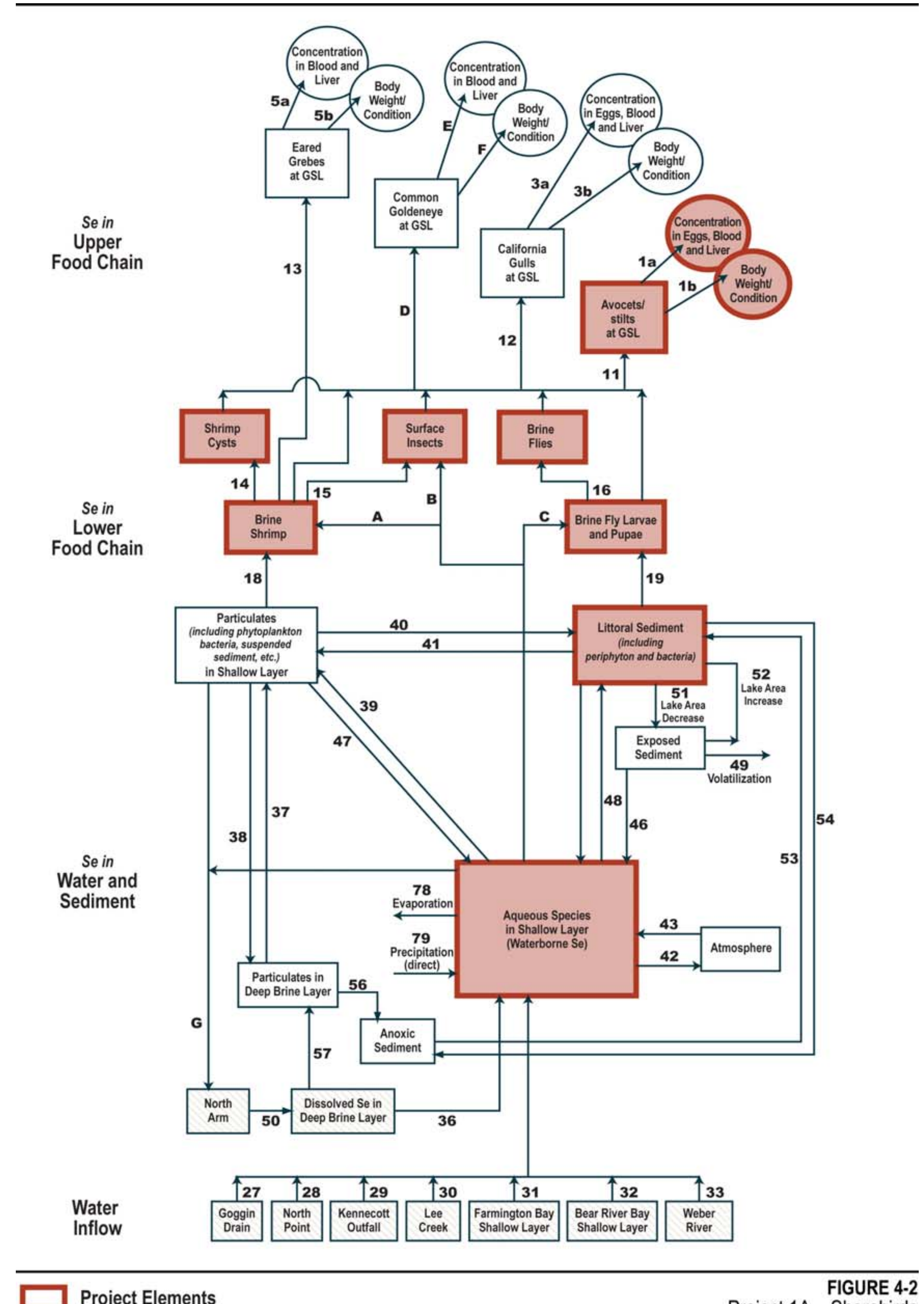

FIGURE 4-2
Project 1A – Shorebirds
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.2 Project 1B, Concentration and Effects of Selenium in Gulls, Grebes, and Ducks

Principal Investigator: Dr. Mike Conover, Utah State University

Project Objectives (2006)

- Determine stomach contents of nesting birds and ambient selenium concentrations in water, sediment, brine shrimp, brine flies, and other identified food items in nesting California gull foraging areas and in bird eggs, blood, and livers
- Determine if selenium concentrations affect reproductive success of California gulls at Great Salt Lake
- Determine selenium concentrations in eared grebes during the fall and male common goldeneyes during the winter, and determine if selenium concentrations affect body condition of those birds

Project Objectives (2007)

- Determine body condition, diet, and ambient selenium concentrations in blood and liver of nesting California gulls from two salt water colonies (Hat Island and Great Salt Lake Minerals) and a “fresh” water colony (Neponset Reservoir)
- Compare blood/liver selenium concentrations and diet found in crop of sampled birds from different nesting sites and opportunistically sample brine shrimp in area where gulls are feeding to link diet to blood and liver selenium levels

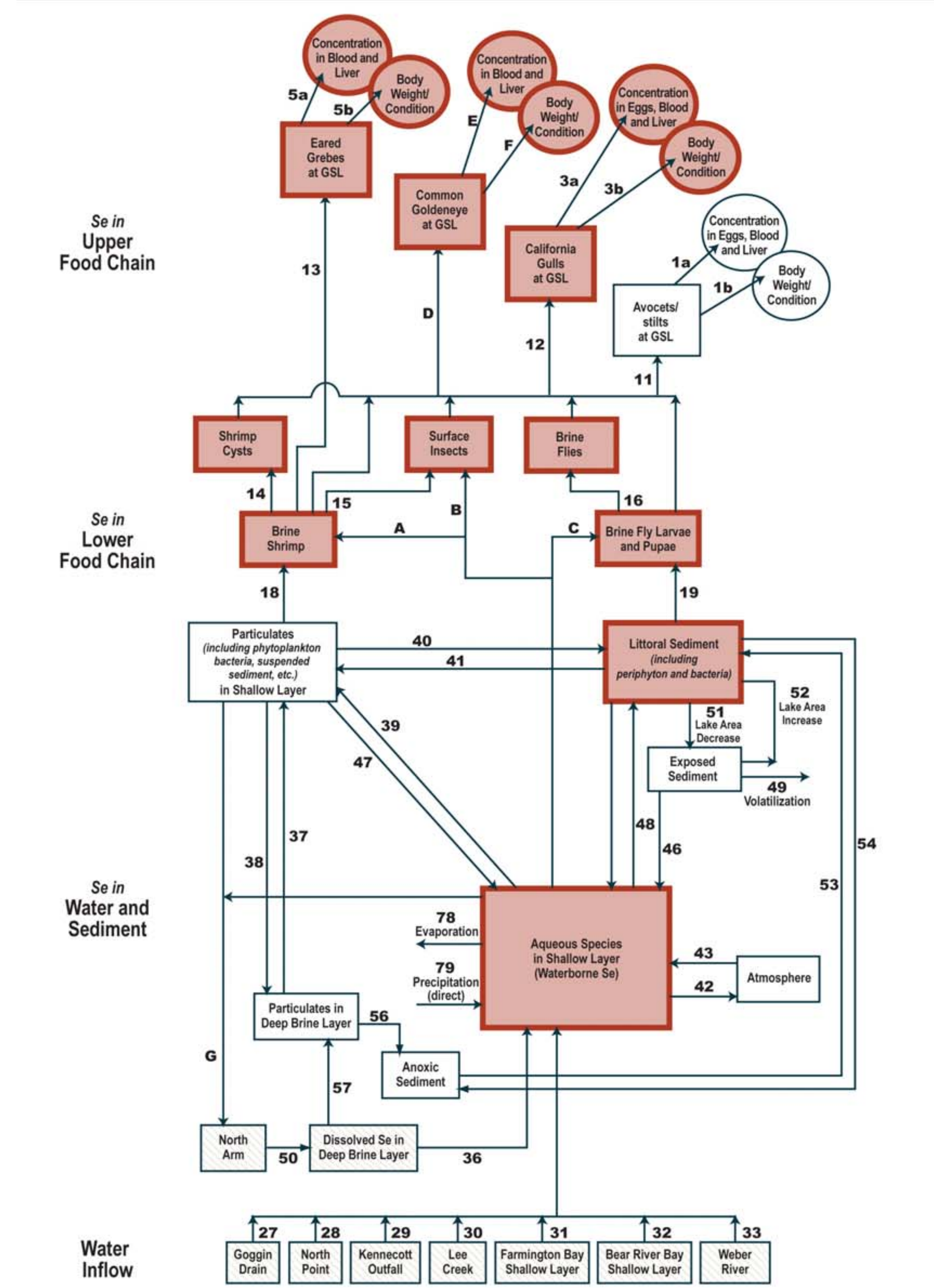
Project Questions

The guiding questions for Project 1B include the following:

- What are the transfer factors for selenium from the diet to bird eggs?
- Are significant ecological effects occurring in California gulls, eared grebes, or common goldeneye? If so, to which ones and at which locations?
- What are the associated selenium concentrations bird eggs, blood, and livers?

To understand the potential effects of selenium on these birds at Great Salt Lake, the following questions needed to be addressed:

- Where do California gulls nest and forage within Great Salt Lake and what is the diet of nesting gulls?
- What are the ambient selenium concentrations in the water, sediment, and diet items at the foraging sites of nesting California gulls in Great Salt Lake?
- What are the associated selenium concentrations in nesting California gulls (blood and liver), a random sample of gull eggs, gull eggs with dead or abnormal embryos, and deformed gull chicks?
- What are selenium concentrations in adult eared grebes staging on Great Salt Lake when they first arrive and right before they leave, and how does body condition of grebes relate to selenium concentrations in their tissues?
- What are selenium concentrations in overwintering ducks (adult male common goldeneye), and how does body condition of ducks relate to selenium concentrations in their tissues?



Project Elements

FIGURE 4-3
Project 1B – California Gulls, Eared Crebes, Common Goldeneye
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.3 Project 2A, Synoptic Survey of Selenium in Periphyton and Brine Fly Larvae from the Benthic Zone

Principal Investigator: Dr. Wayne Wurtsbaugh, Utah State University

Project Objectives

Determine the importance of the benthic food web for bioaccumulation of selenium in birds by:

- Developing methods to sample the benthic zone of the lake
- Determining chlorophyll concentrations in periphyton and selenium concentrations in periphyton brine fly larvae and detritus found on sand, mud, and biostromes (stromatolite) substrates in Great Salt Lake as well as in adult brine flies
- Determining ambient selenium concentrations in co-located water and substrate samples

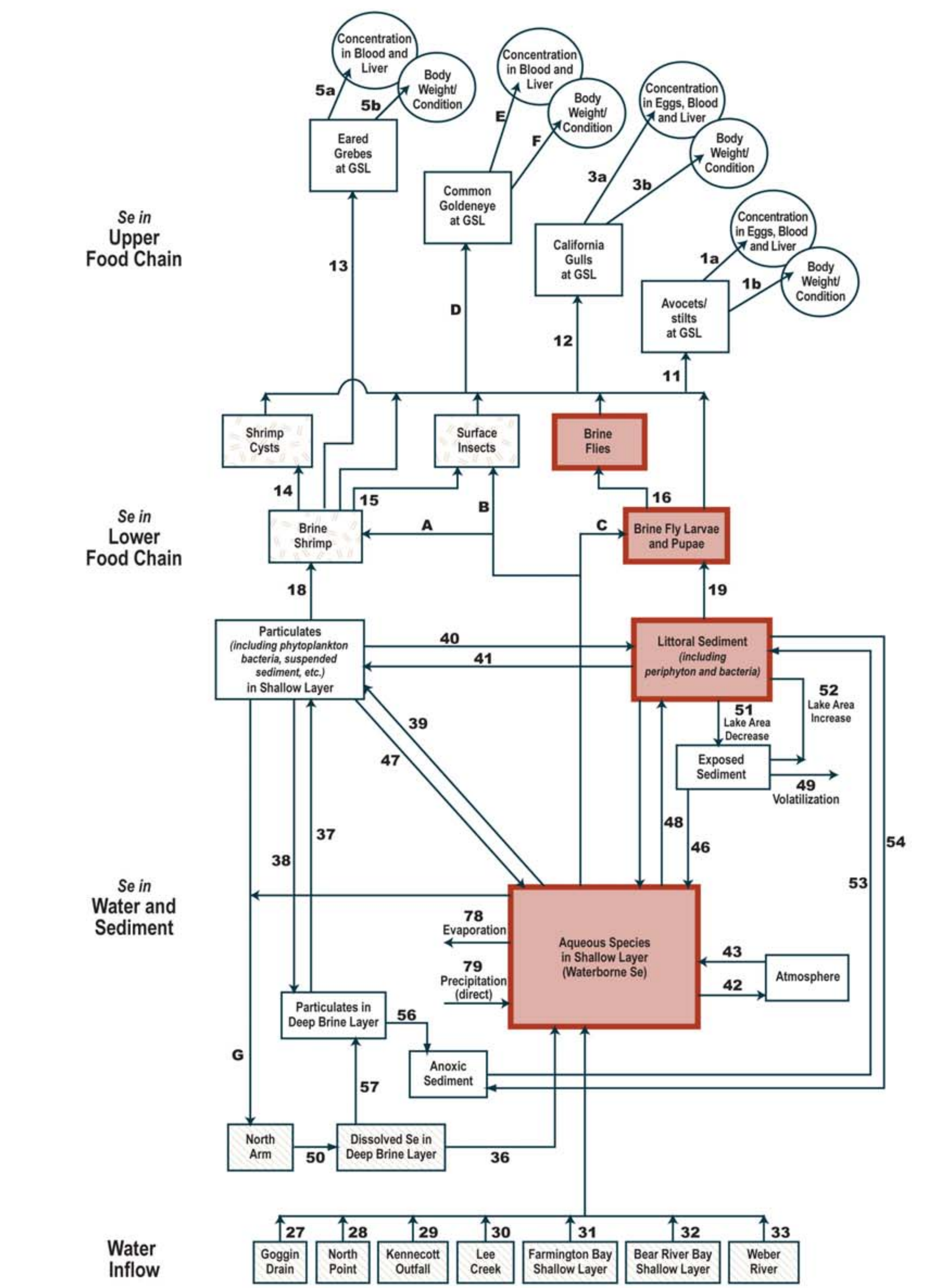
Project Questions

The guiding question for Project 2A was:

- What are the transfer factors for selenium from the benthic zone (water and sediment) to the brine fly component of the food web?

To understand the potential effects of selenium on the benthic zone and food web of Great Salt Lake, the following questions needed to be addressed:

- Can brine fly larvae and pupae be sampled quantitatively using a SCUBA-operated vacuum sampler on stromatolite substrates?
- Can soft substrates be sampled quantitatively using a Ponar dredge?
- What is the time cost for each of these sampling procedures?
- What is the selenium content in periphyton/detrital material?
- What is the selenium content in brine fly larvae and adults?
- What is the selenium content in the overlying water above the benthic substrates?



Project Elements

FIGURE 4-4
Project 2A – Benthic Zone
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.4 Project 2B, Synoptic Survey of Selenium in Water, Seston, and Brine Shrimp

Principal Investigator: Brad Marden, Parliament Fisheries, LLC

Project Objectives (2006)

This project evaluated the trophic transfer of selenium within food webs from water to particulate matter (seston) to brine shrimp (*Artemia franciscana)* through the following objectives:

- Document the temporal and spatial characteristics of total selenium concentrations in water and correlate with seston and brine shrimp tissue selenium concentrations
- Correlate isotopic nitrogen (15N) and carbon (13C) levels in seston with selenium concentrations in brine shrimp tissue to identify dietary sources
- Monitor primary production indicators (chlorophyll a concentration) and record brine shrimp population dynamics (all life stages)
- Document algal population abundance and diversity over time

Project Objectives (2007)

This project was extended to collect samples through July 2007 with the same objectives as in 2006.

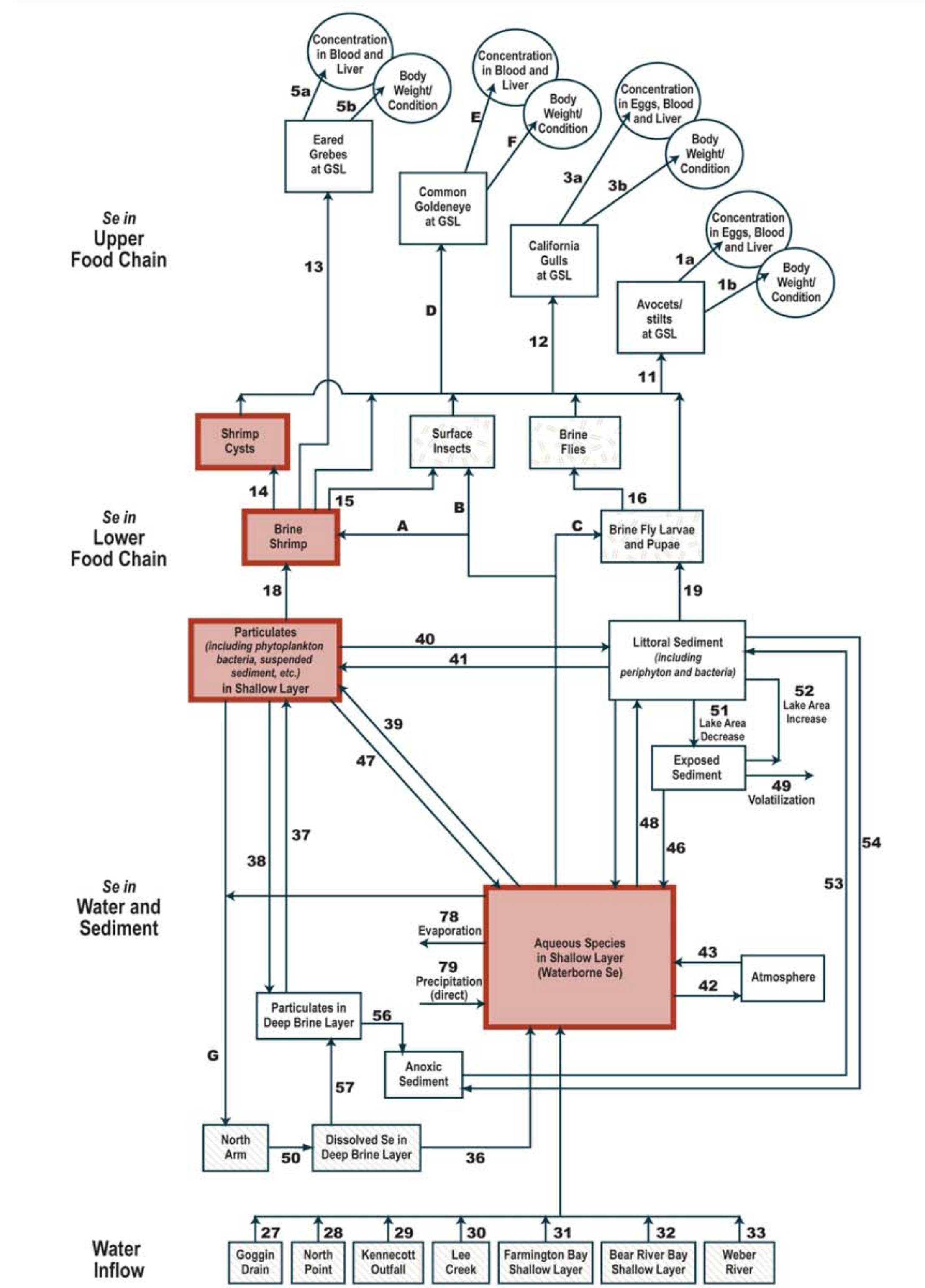
Project Questions

The guiding question for Project 2B was:

- What are the transfer factors for selenium from the pelagic zone (water and seston) to the brine shrimp component of the food web?

To understand the potential effects of selenium on the pelagic zone and food web of Great Salt Lake, the following questions needed to be addressed:

- What are the concentrations of selenium in Great Salt Lake water, seston, and brine shrimp tissue?
  - What is the correlation between waterborne concentrations of selenium and levels found in seston and brine shrimp?
  - What is the potential dietary selenium risk to avian species from consuming brine shrimp (not part of Marden's study)?
- What are the temporal and spatial patterns of isotopic carbon (13C) and nitrogen (15N) in particulate organic matter and brine shrimp tissue as may be indicative of dietary sources?
  - Do 13C and 15N correlate with selenium concentrations in particulate organic matter and brine shrimp?
  - Do selenium, 13C, and 15N in brine shrimp correlate with seston abundance (surrogate forphytoplankton abundance)?
  - Do the stable isotope fractions in diet indicate discrete sources of selenium that account for brine shrimp tissue levels of selenium? Do the sources supporting the brine shrimp body-burdens of selenium vary seasonally?
- What are the population size, age-structure, and biomass of brine shrimp in Great Salt Lake?
  - What is the total selenium load in Great Salt Lake brine shrimp population (How do changing brine shrimp tissue concentrations of selenium and the abundance of adults or cysts correlate with avian consumers and avian seasonality and nesting at Great Salt Lake?)?



Project Elements

FIGURE 4-5
Project 2B – Pelagic Zone
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.5 Project 3, Measurement of Selenium Loads to Great Salt Lake

Principal Investigator: Dr. David Naftz, USGS, Dr. Bill Johnson, University of Utah

Project Objectives

Most rivers that flow into Great Salt Lake are monitored by the USGS with respect to discharge and concentration of chemical constituents. Unfortunately, all of the established gaging sites are located significant distances upstream of where the outflow actually enters the open waters of Great Salt Lake. Significant changes in the selenium concentration, as well as other chemical constituents, can occur between the established gaging stations and where the inflow enters into the open waters of the lake.

The objective of this project was to establish new stream gaging station locations that facilitate the measurement of selenium loads entering the open waters of Great Salt Lake. Data gathered from the new gaging infrastructure were used to model mean daily selenium loads from all surface water inflow sources to Great Salt Lake. The modeling results were used to determine an annual selenium budget for the open waters of Great Salt Lake. For purposes of this project, it was assumed that loading from groundwater and atmospheric deposition was negligible.

Project Questions

The guiding question for Project 3 was:

- What are the sources of waterborne selenium entering Great Salt Lake, and what is the relative significance of each of the various sources?

To understand the relative significance of each of the potential sources of selenium to Great Salt Lake, the following questions needed to be addressed:

- What is the potential selenium load from the following sources?
  - Farmington Bay
  - Bear River Bay
  - Goggin Drain
  - Weber River
  - Lee Creek
  - Kennecott Utah Copper outfall
  - North Arm flow through Union Pacific Railroad Causeway
  - Morton Salt Outfall
  - Great Salt Lake Minerals outfall
- What are the seasonal and geographic variations in selenium loadings with respect to seasonal biological cycles in the Great Salt Lake ecosystem?

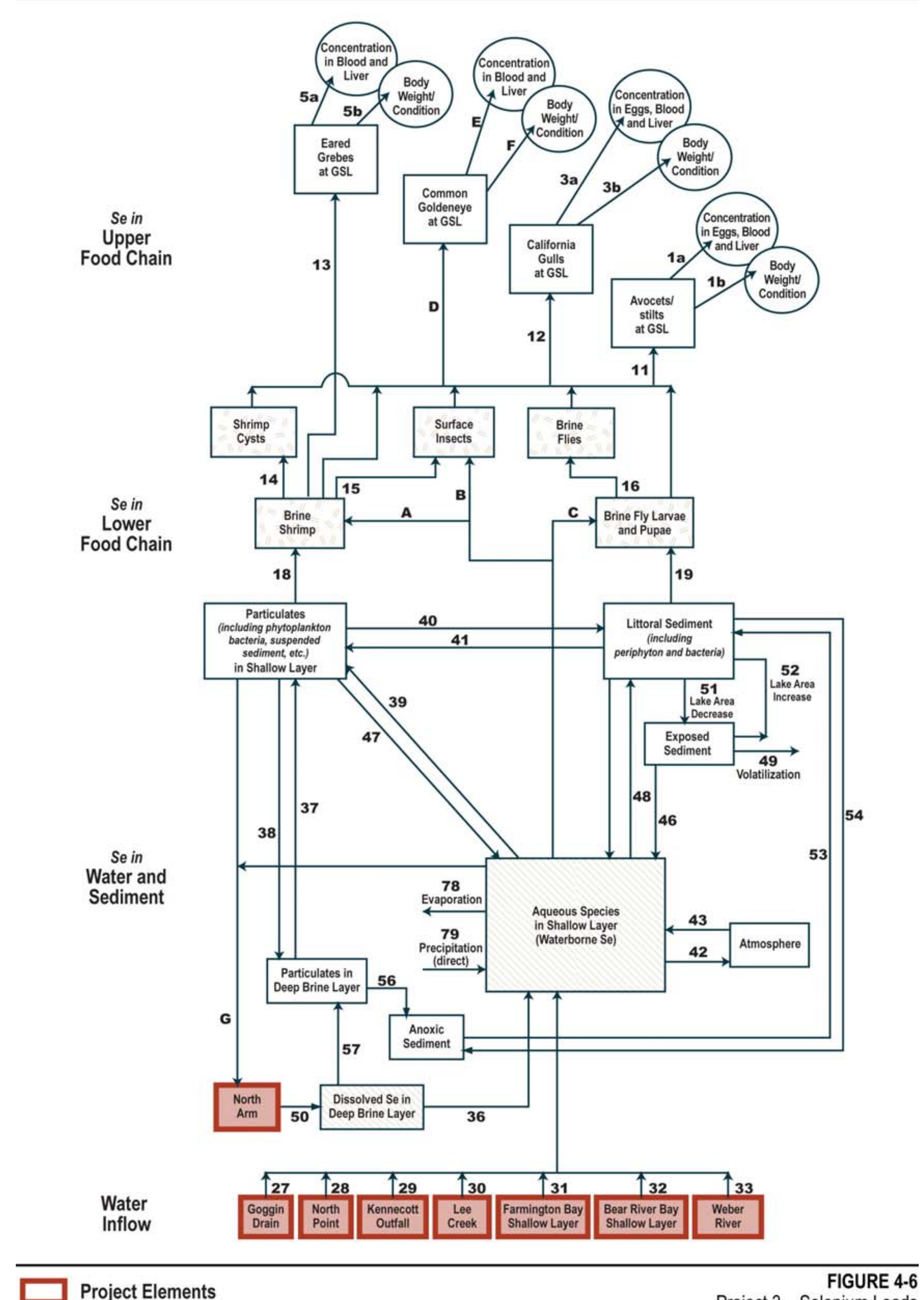

FIGURE 4-6
Project 3 – Selenium Loads
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.6 Project 4, Measurement of Selenium Flux

Principal Investigators: Dr. Bill Johnson, University of Utah; Dr. David Naftz, USGS

Project Objectives

The selenium inputs determined in Project 3 must be balanced against selenium outputs, which are expected to occur mainly via two mechanisms: (1) release of selenium vapor to the atmosphere; and/or (2) permanent burial of selenium in the sediment. These output fluxes cannot be estimated from published literature because these two release processes in Great Salt Lake have not been heavily investigated. Furthermore, the existing literature for other systems does not address a system of the size, salinity, vertical and spatial heterogeneity, and temporal variability as represented in Great Salt Lake.

The objective of Project 4 was to complete appropriate measurements to:

- Estimate the flux rates of volatilization, ebullition, and permanent burial via sedimentation
- Estimate the effects re-suspension and re-solubilization of selenium have in mass balance to the water column
- Estimate the potential internal selenium load to the water column from rising lake levels

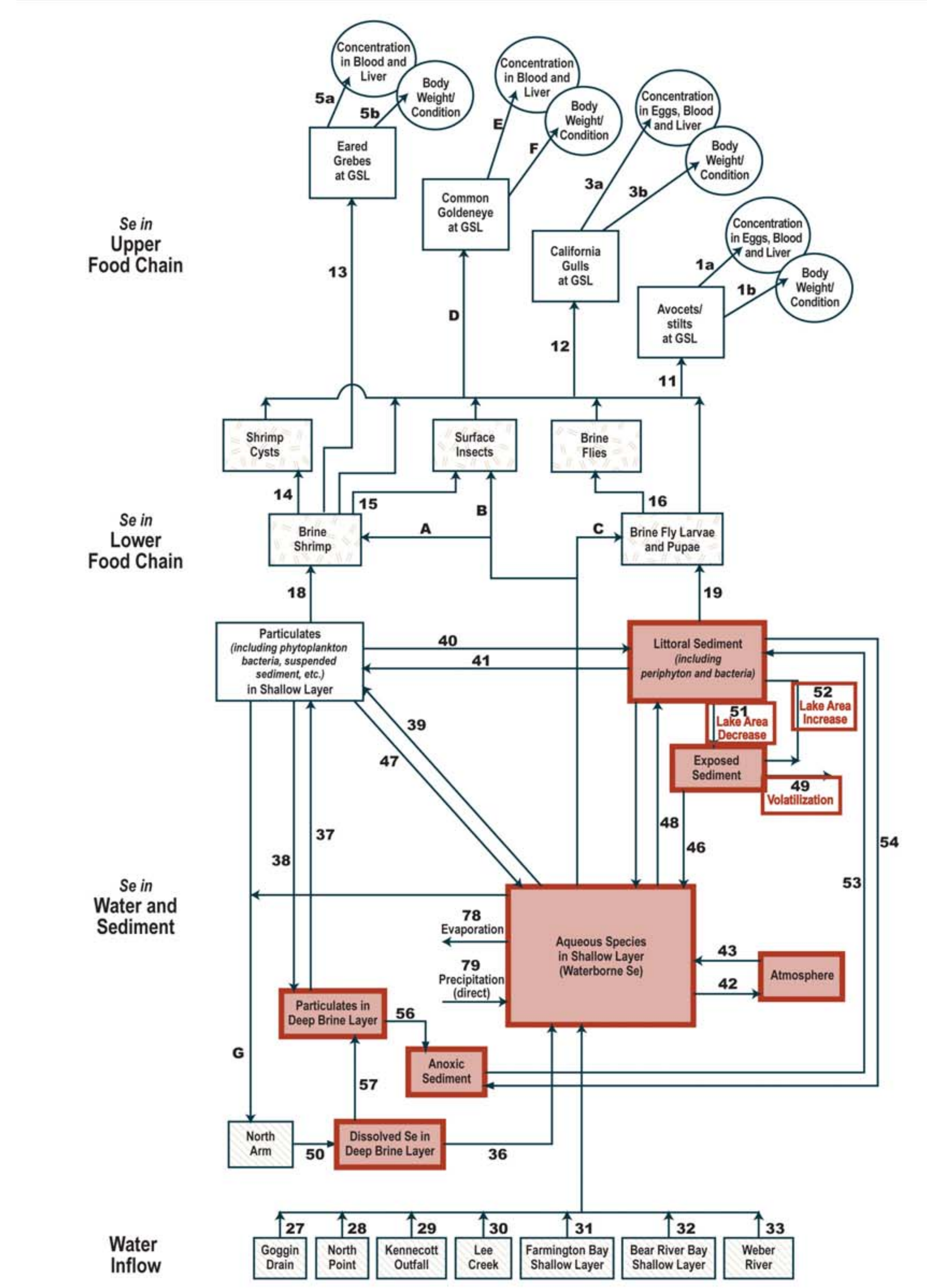
Project Questions

The guiding question for Project 4 was:

- What are the most important processes that affect the partitioning, cycling, and release of selenium in Great Salt Lake open waters (that is, where does the selenium go once it is in Great Salt Lake)?

To understand the partitioning, cycling, and release of selenium in Great Salt Lake, the following questions needed to be addressed:

- What are the rates of selenium removal via volatilization and ebullition from Great Salt Lake?
- What is the rate of permanent sequestration of selenium via sedimentation?
- Do transient events or ongoing processes re-suspend and re-solubilize selenium into the water column to an extent that has biological significance?
- Do lake level rises re-introduce selenium into the water column to an extent that has biological significance?



Project Elements

FIGURE 4-7
Project 4 – Selenium Flux
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.7 Project 5, Predictions of Selenium Accumulation in ***Artemia franciscana*** under Conditions Realistic for the Populations residing in the Great Salt Lake (Brine Shrimp Kinetics)

Principal Investigator: Dr. Martin Grosell, University of Miami

Project Objectives

The primary objective for Project 5 was to provide reliable predictions of selenium accumulation in brine shrimp under conditions realistic for the populations residing in Great Salt Lake.

This general objective was addressed by pursuing the following specific objectives:

1. Determine the influence of salinity on selenium uptake and feeding rate by brine shrimp
2. Determine selenium uptake rates in brine shrimp from dissolved selenium concentrations in artificial Great Salt Lake water (uptake kinetics)
3. Determine dietary selenium intake and subsequent selenium assimilation efficiency in brine shrimp fed a diet of selenium-loaded algae cells (*Dunaliella viridis*)
4. Determine selenium elimination rates from brine shrimp following selenium accumulation from elevated ambient concentrations
5. Model selenium accumulation in brine shrimp based on the results from Objectives 1 through 3 to provide predictions of selenium accumulation during realistic exposure scenarios
6. Determine the "knee" of the dissolved selenium accumulation rate curve in brine shrimp
7. Investigate possible regulation of selenium accumulation in brine shrimp during prolonged exposure to selenium

Project Questions

The guiding question for Project 5 was:

- What are the transfer factors for selenium from water and algae to the brine shrimp component of the food web as determined under laboratory conditions?

To understand the transfer of selenium from water and algae to brine shrimp, the following questions needed to be addressed:

- What is the influence of salinity on selenium uptake and feeding rate by brine shrimp?
- What are the uptake kinetics, assimilation efficiencies, and elimination rates for brine shrimp in artificial Great Salt Lake water and shrimp fed a diet of selenium-loaded algae cells?
- What is the "knee" of the dissolved selenium accumulation rate curve in brine shrimp?
- How can we predict how selenium will accumulate in brine shrimp during realistic exposure scenarios?

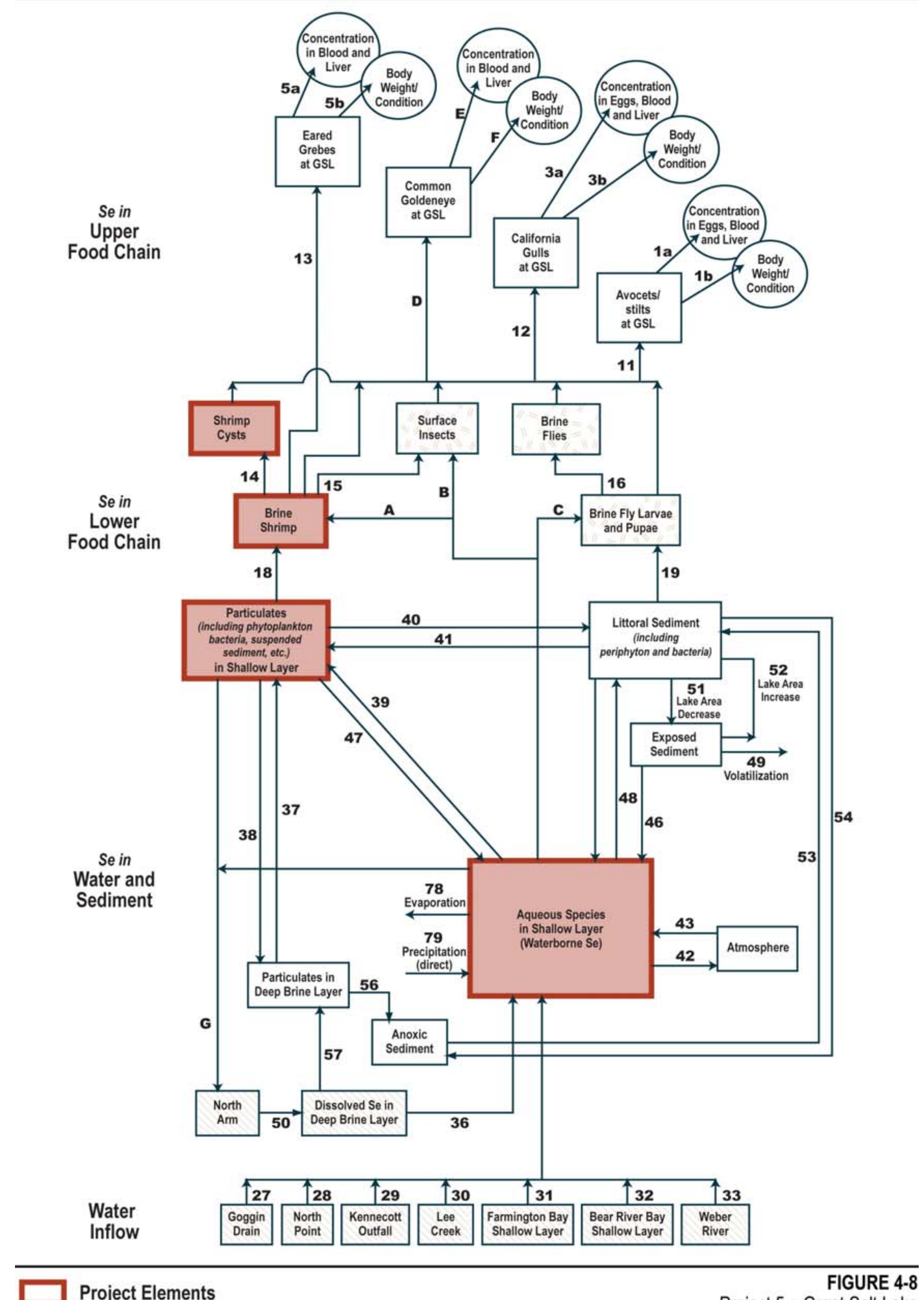

FIGURE 4-8
Project 5 – Great Salt Lake
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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